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Dynamics of hydraulic properties due to biological clogging

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Classic treatment of soil-water flow is described by the unsaturated version of Darcy's law and Richards' equation, assuming time invariant hydraulic properties, e.g. the saturated hydraulic conductivity, Ks, and van Genuchten-Mualem's α and n. However, when bacteria is present the soil is quite far from being time invariant and biological activity constantly alters the pore-scale structure, leading to macro-scale alteration of the hydraulic properties. This may be of high relevance to processes such as subsurface bioremediation, soil aquifer treatment, wastewater irrigation, and more. In this work we explore the dynamic alteration of soil hydraulic properties by a combination of column experiments and pore-network modeling. We experimentally demonstrate how biological activity clogs an unsaturated soil column and reduces its hydraulic conductivity, while a similar column where biological activity is limited does not clog. Further, we demonstrate that the clogging is preferential to the nutrient input. Next, we develop a pore-network model that uses triangular shape channels. This allows a dual occupancy (water-air) of each channel and high connectivity. The model solves the flow of water, nutrient transport, and biological dynamics. It includes biofilm growth and decay, attachment and detachment, and nutrient exchange between the water and biofilm phases. We perform a sensitivity analysis of the model and qualitatively show through the loss of connectivity how the clogging that was observed in our experiment can be explained.